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Hudson River Bridge

ROEBLING
CABLES



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FOR THE

HUDSON RIVER BRIDGE



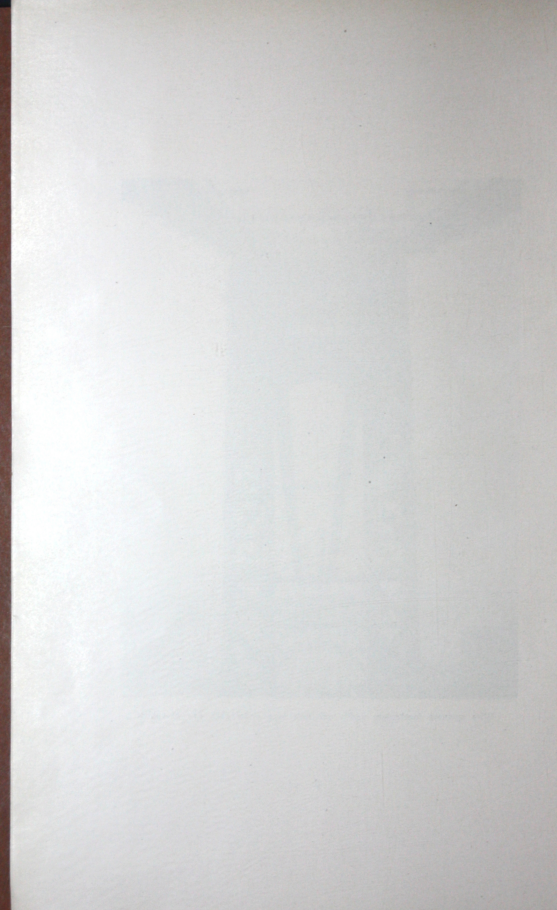
PROBLEMS AND REQUIREMENTS
RESEARCH
MANUFACTURE
PLANT INSTALLATION
CABLE STRINGING EQUIPMENT
CABLE SPINNING
STRAND ADJUSTMENTS
VITAL ROEBLING DEVELOPMENTS

Prepared and edited by
FRANK W. SKINNER
Consulting Engineer





Wire spinning footbridges nearly one mile long under each pair of cables.

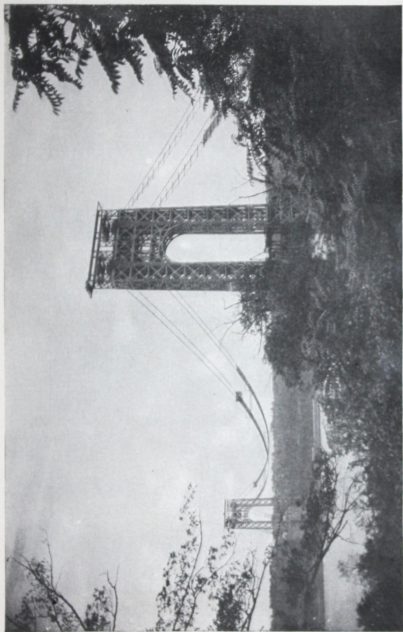


THE HUDSON RIVER BRIDGE

Only a few years ago the construction of a span as long as that of the Hudson River Bridge was pronounced impossible by high authorities. Later it was admitted practicable, but believed to be unprofitable. Now it has become imperative, and a single span structure of unprecedented dimensions, capacity and cost has reached such a degree of highly successful erection that its early completion is well assured, and it is timely to outline some novel and important features of cable construction while they are still in progress or visible.

This brief presentation emphasizes essential developments, the creation of new high standards, and the applications and improvements of scientific and mechanical investigations, methods and equipment, that have assured great safety, efficiency and economy never before approached on similar work, and without which this work could not have been executed with the speed and proficiency that have been attained. It marks a very long stride in bridge construction, and demonstrates the advance of manufacture and erection fully equal to exacting requirements of engineering progress.

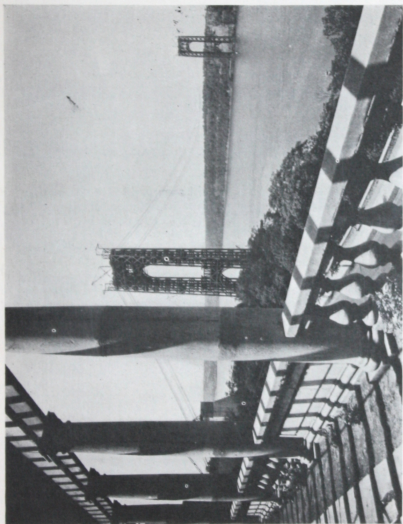
Competitive bids on alternative designs for parallel wire or eyebar cables gave a difference in favor of the former, and the contract for wire cables was awarded, on its merits, to the John A. Roebling's Sons Company, Trenton, N. J., for \$12,339,977.00 for the construction of the 28,600-ton cables, the fabrication and some of the erection of more than 7,000 tons of structural steel in the anchorages and approach floor, and for the fabrication and erection of 34 miles of $2\frac{1}{8}$ -inch diameter rope.



Footbridge during construction, while its cables were illuminated by flood lights on the tower tops for the protection of aeroplane traffic.

The John A. Roebling's Sons Company has been actively engaged in the design and manufacture of wire for, and in the erection of suspension bridge cables, for a longer period than any other firm in this country. From a small beginning in 1841 at Saxonburg, Pa., transferred to Trenton, N. J., in 1848, this company has designed and built many long and short span suspension bridges, and since its long ago construction of the famous Niagara and Brooklyn bridges, it has maintained a continuous, active and progressive interest in suspension bridges.

Eminently qualified by this exceptional background of tradition, experience and accomplishment, the Roebling Company successfully undertook the long, difficult and costly research and design resulting in more than thirty new features and details of equipment and methods which are now playing such an important role in the erection of the main cables of the new Hudson River Bridge.

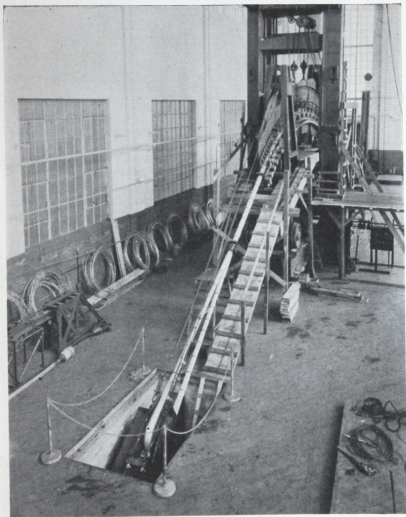


Footbridge cables in place, and Roebling construction towers being erected on top of main tower.

PROBLEMS AND REQUIREMENTS

The Roebling Company is held responsible for the quality of materials, and safe and prompt completion of their contract in strict accordance with specifications of the Port of New York Authority.

Requirements were high; difficulties great; time short; and there were no precedents of anywhere nearly equal magnitude; therefore the Company assigned a corps from its permanent staff of engineering specialists to preliminary researches and verifications, including analyses, experiments, full-size and model tests, and the study and development of new and improved equipment and methods. This work was carried on for more than a year prior to the commencement of field operations.



Strand friction test at Trenton plant of John A. Roebling's Sons Co. Full size strand built through 2,500,000-pound testing machine to establish friction value between main tower saddles and strands.

The apparent impossibility of stringing the four cables simultaneously in the very short specified time caused the consideration of methods of stringing them in successive pairs; model tests and computations demonstrated so many difficulties in this method that improvements in spinning mechanism and operations were developed that permitted the cables to be spun simultaneously much more rapidly than was ever before possible.

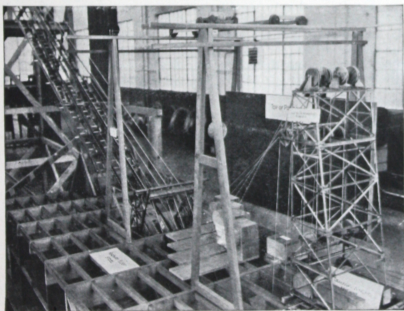
Full size experimental cable wire spinning apparatus was erected at the Kinkora plant and its operation was studied; new devices and improvements were developed until eventually a wire spinning speed 100% faster than ever before practised was attained.

A new spinning wheel was perfected that eliminates the hanger goose neck, the use of which definitely limits the tramway speed.

A system of counterweight take-ups in towers maintains uniform tension in the wire while spinning, and affords a gauge for the instantaneous synchronization of the unreeling machines with the spinning wheels; a very important operation.

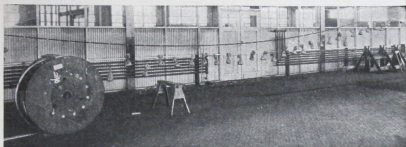


Cable wire spinning wheel attached to aerial tramway

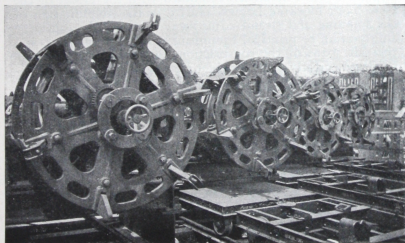


1/20 scale model of counterweight tension tower and girder crane supported on floor steel, New Jersey.

In former practice the cable wire reels were overhauled by the spinning wheel, and irregularities of unwinding or speed produced exceedingly troublesome variations of momentum. With reels weighing twice as much as formerly, this would be very serious, and has been obviated by mounting the reels on power driven and power braked unreeling machines that quickly engage and disengage, load and unload, start and stop the reels and regulate their speed instantly.



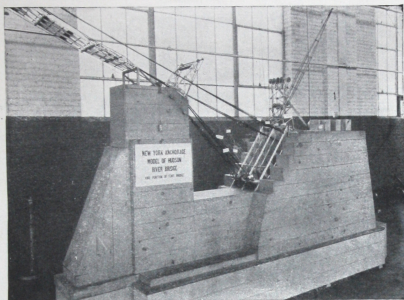
1/24-Scale model and sand bag loading of main cable for study of successive cable spinning operations.



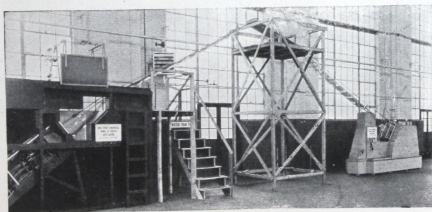
Unreeeling machines from which all cable wire is spun under perfect control.

The arrangement of cable wire spinning apparatus, including the aerial tramway for operating the spinning wheel, its special support, tension tower and other details, were shown on a model of the New York anchorage together with one end of the side span footbridge.

A 1/24 scale model of the New Jersey tunnel anchorage was made, and afforded opportunity to study the clearances of the eyebars and girders therein, and to develop their erection methods. The model, combined with the model of the New York block anchorage, assisted in the simplification of the spinning and strand adjustment studies. Arrangement and location of principal equipment was made on them, and the side spans of the construction footbridge were also reproduced, greatly assisting the draftsmen to visualize conditions and requirements.



Model of New York anchor block showing footbridge cables, wire tension tower, traction tramways and supports.



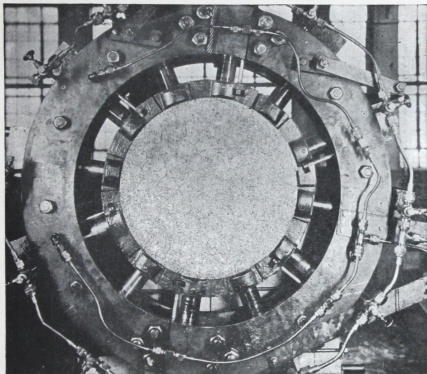
Model to 1/24 scale showing anchorage eyebars and strand connections, and portion of footbridge, with spinning equipment mounted on anchor block.

To study the effects of compression on a main cable composed of 26,474 wires, each 0.196 inch diameter, a short length of cable with full size cross section was made and tested for friction, compression, distribution of stress and other features. Test wires were left protruding from the end of the cable to study their resistance to longitudinal displacement when under transverse pressure.



Full size cable section under circumferential pressure. Wires projecting from one end to be pulled.

A full size yoke, to be eventually used for compacting the finished cable, was used to compress the experimental cable. It was provided with twelve radial hydraulic pistons, together exerting a balanced pressure of about 400 tons, that compress the 61 strands from their original hexagonal arrangement, with numerous voids between them, to a substantially solid cylinder approximately 36 inches in diameter, in which an indication of the original strand outlines is scarcely perceptible.

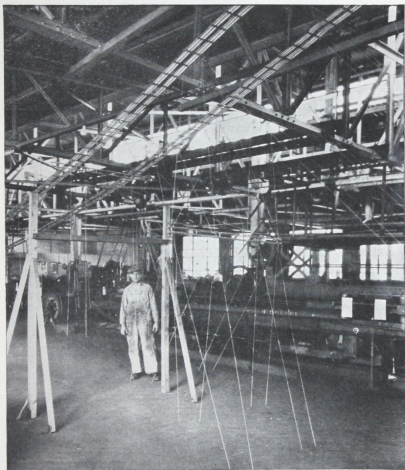


Full size cable section in compression machine, showing strands compacted as in finished cable.

The displacement by wind of the temporary working platform or footbridge from which the main cables are strung is so great that in former work it has often interrupted operations, and the limits of permissible displacement had been nearly reached in the maximum span lengths attained.

When these were doubled in the Hudson River Bridge, new provisions were desirable to make the footbridge more stable. Therefore elaborate investigations were made on the vibrations and distortions due to displacements and the damping effects of retarding elements.

Many systems were tried, and finally an independent funicular system combined with horizontal transverse suspended compression booms, was developed that demonstrated the possibility of securing astonishing stability for the long span.

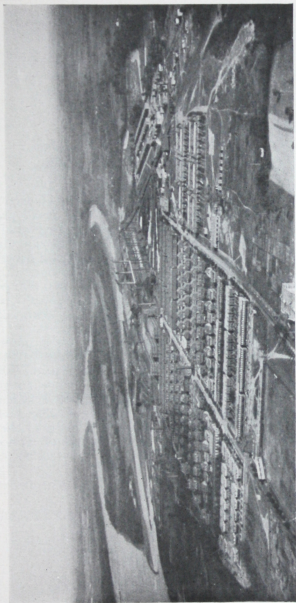


1/35 scale model of center span footbridge and storm system, showing compression boom.

WIRE MANUFACTURE

All of the cable wire and wire ropes for the Hudson River Bridge are manufactured in the three plants of the Roebling Company. These plants together cover an area of about 213 acres and employ about 4,000 skilled and semi-skilled workmen.

Recently most of the remaining power boilers have been replaced by electric current which operates 1,100 motors and the lighting plants. Steam is used for processing and for heating, and compressed air for pneumatic hoists and for oil fuel burners.



Kinkora plant of John A. Roebling's Sons Co., where all wire for Hudson River Bridge is made. Village of Roebling, N. J. in foreground.

CHARACTER OF ROEBLING WIRE

The bridge wire in the main cables of the Hudson River Bridge is of the same character as that used in all previous suspension bridges having Roebling cables, beginning with the Brooklyn Bridge, in which the wire has an ultimate strength of 160,000 pounds per square inch, and progressing chronologically with the Williamsburg Bridge, 200,000 pounds per square inch; Manhattan Bridge, 210,000 pounds per square inch; Bear Mountain Bridge, 215,000 pounds per square inch, and the Hudson River Bridge, with 225,000 pounds per square inch.

The average strength of the last 4,000,000 pounds of cable wire tested for the Hudson River Bridge is 240,000 pounds per square inch. Tests on the first 45,000,000 pounds of wire furnished for this bridge show an average tensile strength of 235,000 pounds per square inch, and this steadily sustained increase in the strength of cable wire, and the fact that it is all standard cold drawn wire, of the same character that has successfully stood the test of services for many years, gives full assurance of the durability of the cables.



36 reels, 288 tons, of bridge wire ready for shipment

The superiority of the Hudson River Bridge cable wire over any wire previously furnished for a similar project is due to the quality of materials; extremely careful and highly skilled operations, and perfected galvanizing.

Important items of improved wire manufacture are: the selection of raw materials; method and extreme care in the steel production; selection of heats; very close analyses of chemical constituents; close observation of refining and tapping temperatures; the rolling of ingots and billets that produce rods free from seams and surface defects. All these refinements in the production of the semi-finished steel and the rods, and the use of acid open hearth steel make for high wire quality and uniformity.



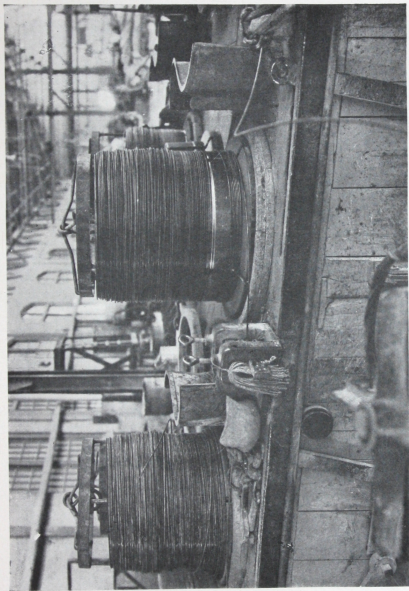
Billets in storage pile ready to go into wire rod mill at Kinkora plant of John A. Roebling's Sons Co.,
Roebling, N. J.

WIRE DRAWING AND GALVANIZING

The physical properties of the wire are highly developed by the cumulative meticulous care constantly maintained in every detail of the manufacturing processes.

The actual wire drawing process insures great uniformity of diameter and physical qualities, which are practically the same from one end of a coil to the other.

Coils of wire rods are cold drawn again and again, through smaller and smaller holes in steel dies, until they are reduced to the required diameter of about $6\frac{1}{4}$ thirty-seconds of an inch, elongated to a length of 3,800 feet, and have their strength increased until a value of about 260,000 pounds per square inch is obtained. The strenuous work of drawing insures the great strength of material necessary to resist the drawing stresses, and the process is so efficient that the surface of the wire is perfectly smooth and the diameter is very uniform from end to end. The Roebling shops are equipped with 48 sets of wire drawing blocks suitable for the Hudson River bridge cable wire, but only half of them are required to meet the erection schedule.

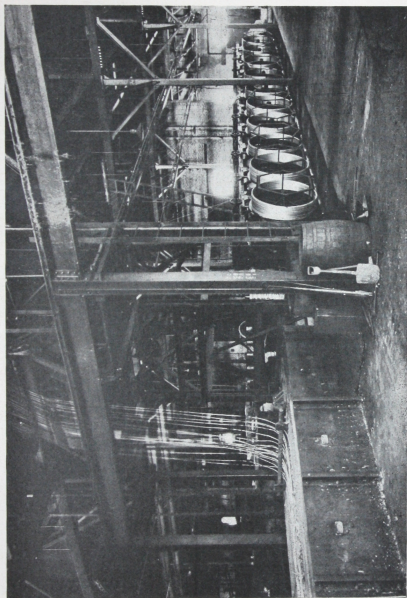


Drawing bridge wire at the Kinkora plant, Roebling, New Jersey (this wire drawing shop has a capacity of 5,000,000 pounds per month of bridge cable wire, and is producing 2,500,000 pounds per month to keep pace with the spinning of the Hudson River Bridge cables, and maintain an adequate reserve supply for them).

The most modern methods of galvanizing produce on the finished wire a uniform zinc coating that adheres most tenaciously.

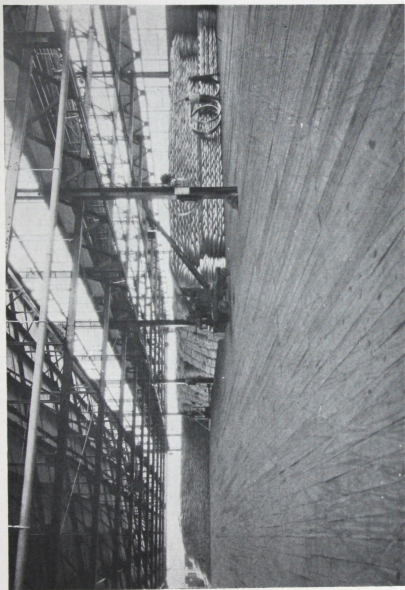
Twenty lines of wire are continuously passed through successive baths of melted lead to heat them, through dilute acid to clean them, and through molten zinc to galvanize them, after which they are drawn over an elevated drum, washed and finally coiled for testing and storage.

During this process they are uniformly coated with a very durable, tenacious zinc skin from $1/1000$ to $2/1000$ inch thick that, so long as maintained continuous and intact, prevents the possibility of corrosion of the steel.



Simultaneous galvanizing of twenty Hudson River Bridge cable wires, passing continuously and uninterruptedly through the zinc bath which deposits on them a coating of solid zinc from 1/1000 to 2/1000-inch in thickness.

The coils of galvanized cable wire for the Hudson River bridge are delivered by electric crane trucks to a great storage warehouse, where thousands of tons are piled awaiting reeling and shipment. Each coil bears a metal tag giving the heat and other numbers by which its test record can be identified, and its record traced back through the rods, billets, blooms and ingots, to the raw products charged into the acid open hearth furnace.

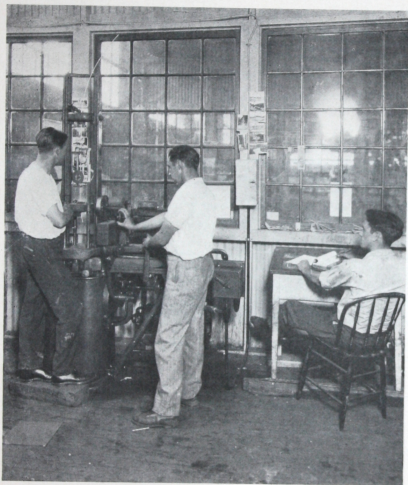


Section of Hudson River Bridge wire storage warehouse containing approximately 20,000,000 pounds of cable wire, each coil of which has been tested at both ends and accepted.

WIRE TESTING

In the Roebling Company's testing laboratory, specimens cut from *both* ends of every coil of Hudson River bridge cable wire are broken in power machines which determine the ultimate tensile strength, ultimate elongation, and yield point, which, at first exceeding the requirements of the specifications, show continual gradual improvement as the quality of raw materials and the care in every stage of manufacture is maintained, with greater and greater uniformity and skill developed by repetition so long continued.

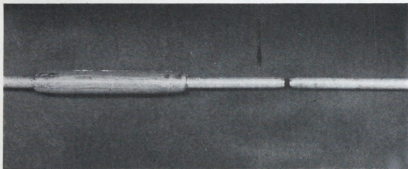
The Port of New York Authority specifications for the Hudson River Bridge require an average minimum yield point stress of 153,000 pounds per square inch; the actual average up to January 1st, 1930, is 182,000 pounds, thus establishing high quality and value, hitherto believed impossible for cold drawn bridge wire, which have been secured on the basis of 45,000,000 pounds production.



Method of testing Bridge cable wire by the Roebling Company, for ultimate strength, ultimate elongation, and yield point.

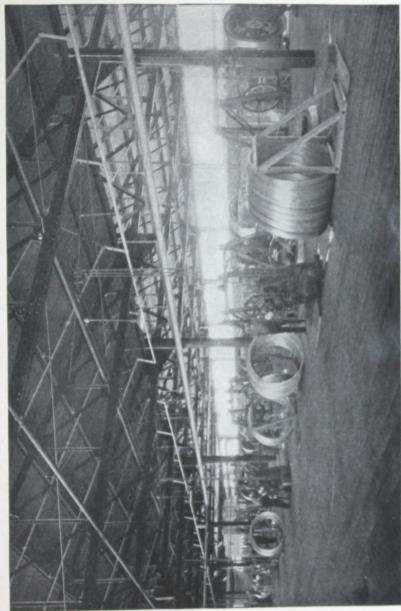
WIRE SPLICING AND REELING

A very important feature of the cable wire is the improved cold pressed sleeve splice, which in a large majority of numerous tensile breaking tests has broken the wire beyond its splice. This assures practically unimpaired maximum strength, and unlimited lengths of wire made from any number of separate pieces that may be quickly spliced either in the shop or field.

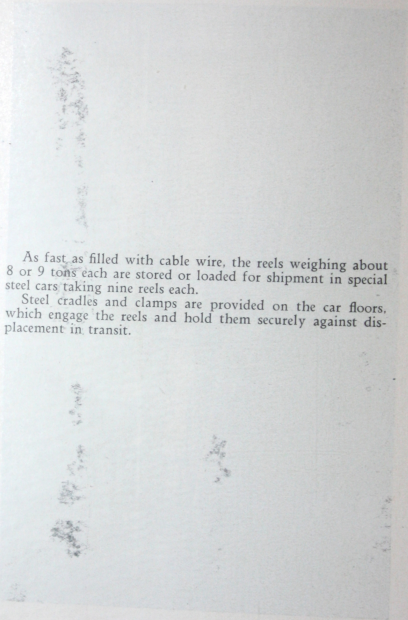


Failure of wire in splice test. Clean cup-and-cone break of wire outside of splice showing a better than 100% connection.

The 3,800-foot coils of tested and accepted finished cable wire are wound under uniform tension on mechanically driven structural steel reels holding 140,000 feet or more of continuous wire, the end of one coil being spliced to the beginning of another coil as the winding progresses.

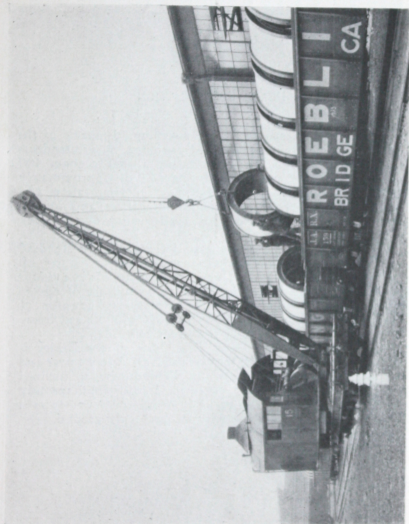


Bridge wire reeling stands in shop at Kinkora plant.



As fast as filled with cable wire, the reels weighing about 8 or 9 tons each are stored or loaded for shipment in special steel cars taking nine reels each.

Steel cradles and clamps are provided on the car floors, which engage the reels and hold them securely against displacement in transit.



Loading reels of bridge wire in special cars at Kinkora plant for shipment to bridge site.

PLANT INSTALLATION

No pains were spared by the Roebling Company in the selection of able and experienced engineers, superintendents and skilled employes, that have reached a total of about 400 men at the site, with a daily payroll of approximately \$6,000. Abundant provisions made for their safety, efficiency and comfort, have resulted in notable zeal and loyalty, and in the rapid execution and high quality of the work performed.

The plant and equipment installed are of high standard design and quality, and include many special appliances, all operated by electric power, and arranged to obviate delays from breakdowns or replacements, an abundance of reserve being always maintained. The average consumption of electricity for light and power is about 50,000 kw hours of 440-volt, 3-phase, 60-cycle current monthly.

All material for the New Jersey side of the Bridge is delivered by barges to the foot of the New Jersey tower and thence hoisted to the top of the Palisades by an inclined cableway arranged to raise or lower a load simultaneously with its traversing, so as to let it travel continuously at a uniform height above the sloping surface of the ground.



Upper end of hoisting cableway on New Jersey shore, derrick mounted alongside of approach cut, commanding anchor block in cut.

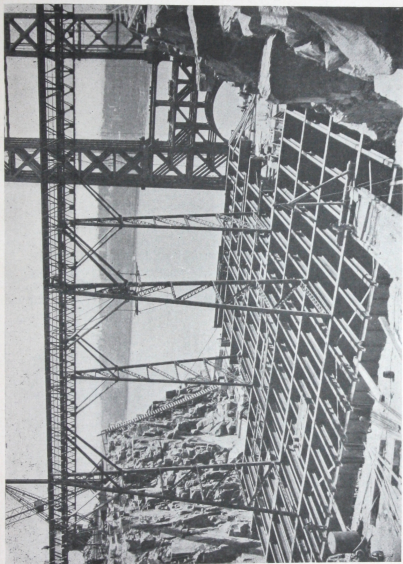


A very complete construction plant and equipment was installed at the bridge site by the Roebling Company at a cost of more than \$1,500,000 and, besides that directly required for the cable stringing operations, included a number of large and small offices, shops, warehouses and other buildings on both sides of the river, cantilever steel dock, a 600-foot and a 750-foot Blue Center cableway, for transferring men, materials and equipment horizontally and hoisting them 300 feet, a 112-foot suspension service bridge, five boom derricks, one 10-ton girder crane of 54-foot span on a 268-foot runway commanding the New Jersey anchorage and storage yard, a 10-ton caterpillar crane and two 7½-ton skip hoists operated on the outer faces of the main towers.



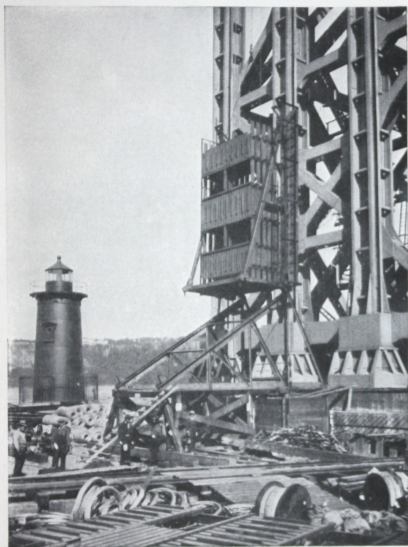
New Jersey approach cut and side span footbridge. Material handling crane in foreground.

The wide and deep rock cut in the top of the Palisades for the New Jersey approach to the bridge, and for its anchor pits, is spanned by the runway of a girder crane that serves the elevated storage yard north of the cut, and also carries a footbridge over the cut.



New Jersey anchorage floor steel furnished and erected by the McClintic Marshall Co., under Roebling contract. Also crane runway for handling reels of bridge wire and other materials and equipment at the New Jersey anchorage.

A special skip, traveling on vertical guide strands from the foot to the top of each tower, transported the footbridge sections and flooring to the temporary working platforms, whence they were delivered to the travelers that erected the footbridges.



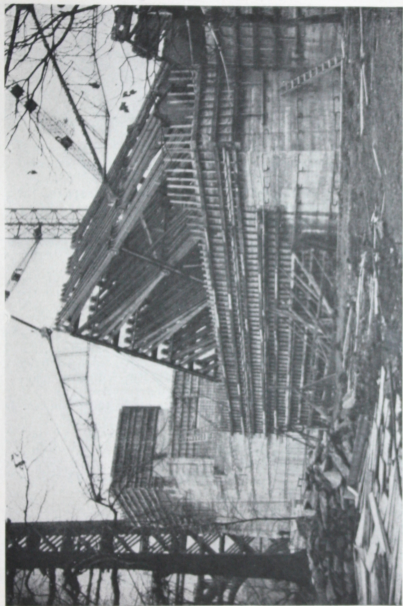
Loaded skip hoist on New York tower.

ANCHORAGE ERECTION

All of the 727 tons of plate girders in the New York anchorage and the 1,426 tons of embedded eyebars in the anchor chains, were furnished by the American Bridge Co., under the Roebling Contract.

On the New York side of the river all the steel was set in the open on the concrete footings which later became integral portions of the huge masses of enclosing concrete that resist the upward and horizontal pull of the cables. The embedded steelwork was set by the Arthur McMullen Co., of New York, who built the New York anchorage and the New York tower foundations.

The 122 lines of eyebars, 2 panels in each line, that were set before cable spinning was commenced, were temporarily supported in their required inclined positions on structural steel transverse bents that remained permanently in position after the eyebars had been sealed up in the great mass of anchorage concrete.



Embedded eyebars in New York anchorage, furnished under the Roebbing contract.

The installation in the two New Jersey anchorage tunnels of twenty 35-ton plate girders, and 1,464 10 x 1 $\frac{3}{4}$ and 10 x 1 $\frac{1}{2}$ -inch eyebars, about 40 feet long, required the transportation and accurate placing of long, wide, and heavy members on steeply inclined surfaces and in very narrow quarters with small clearance. It was successfully accomplished with methods and equipment developed by study and experiment with large scale models.

The girders were trucked ten miles to the top of the Palisades, delivered in the approach cut, derricked to the tunnel top, and there placed on skids and lowered to the bottoms of the tunnel by gasoline hoists.

When the reaction girders reached the bottoms of the anchorage tunnels, they were hoisted to inclined positions at right angles to the anchor chains by tackles suspended from the steel bents provided for the subsequent temporary support of the eyebars, and were jacked transversely to their required positions and bolted in place ready to be pin-connected to the lower panel of eyebars.

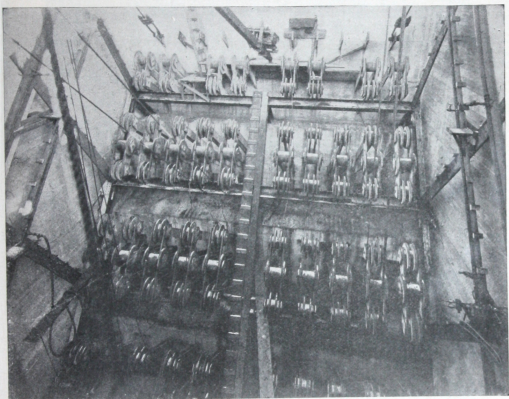
The erection of these girders and the eyebars, and their enclosure with concrete was one of the items of the Roebling contract.



Reaction girder on skids for lowering to position in anchorage tunnel.

Maximum clearance, that was especially needed at the New Jersey anchorage, for the connections of the strand shoes to the anchor eyebars, was secured by the expedient of successively connecting the eyebars in the upper tier to those in the next lower tier, only as fast as their respective strand shoes become ready for adjustment.

Before strand adjustment was commenced, the upper ends of the eyebars projected only a short distance from the anchorage concrete to receive the upper tier bars that were assembled to them from the bottom up, thus always maintaining open working space above them.



Lower panels of New York anchorage eyebars for two main cables ready for successive connections with upper tier of eyebars that engage the strand shoes. Boom for handling equipment above. Pipes from hydraulic pumps, on the walls. Pressure tubes to strand pulling jacks, at lower right corner.

The 2,837 tons of eyebars for the New Jersey anchorage were delivered by lighters to the foot of the tower, unloaded by a derrick boom, and transported in sets of eight in slings hoisted to the top of the anchorage at the rate of 40 eyebars per hour by the inclined cableway. Part of them were lowered to position in the tunnels by whip lines from a gasoline hoist; the bars taking bearing on I-beam skids through rolling pins in their eyes. The eyebar erection was expedited by handling part of them with a 215-foot Blue Center cableway in the roof of the north tunnel.

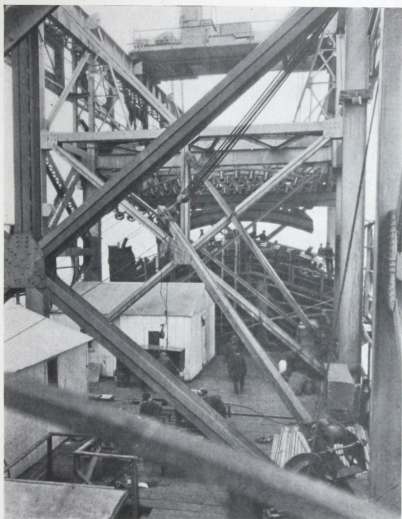
After the lower three panels of eyebars were set they were embedded in concrete that was chuted to position, completely filling the lower ends of the tunnels.



End view of anchorage eyebars connected to reaction girders in tunnel.

CABLE SPINNING EQUIPMENT

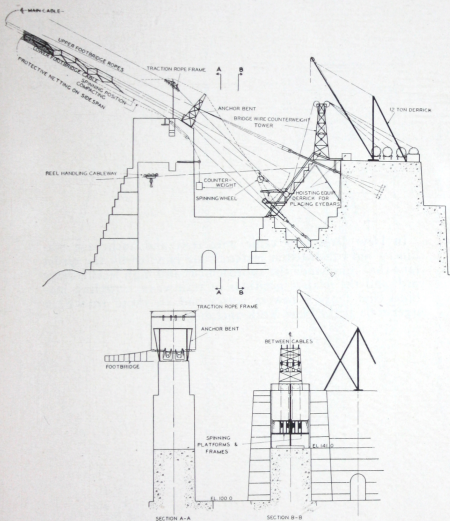
For handling cable stringing apparatus and for other erection service, there is installed on top of each main tower a structural steel framework about 50 feet high, called a construction tower, that supports the cable spinning tramways and other equipment, and has longitudinal girders 245 feet long that cantilever beyond the up and down stream faces of the tower, and serve as runways for the 130-ton girder cranes used for strand shifting and adjusting, instead of jacks, always heretofore used for this purpose.



Roebling construction tower, and 130-ton crane atop New Jersey tower.

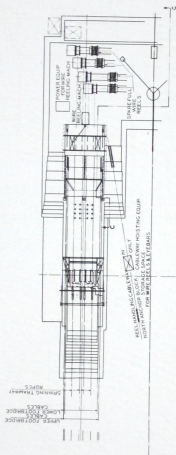
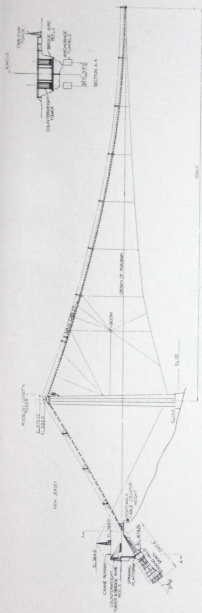
The general arrangement of the wire spinning and strand adjustment plant is substantially the same on both sides of the river, except for variations due to different topography, and to those developed to conform to the tunnel anchorages in New Jersey and the concrete block anchorages in New York.

The completion of the New York anchorage blocks before cable work was commenced provided advantageous support at convenient locations for the important equipment, which was largely installed by the 125-foot boom steel derrick mounted on top of the main block to command its entire area and the adjacent ground area where materials were delivered to it by the inclined cableway. Nearly all this equipment was installed in duplicate for the north and south pairs of cables. The traction rope frame is similar to those installed on the tower tops.

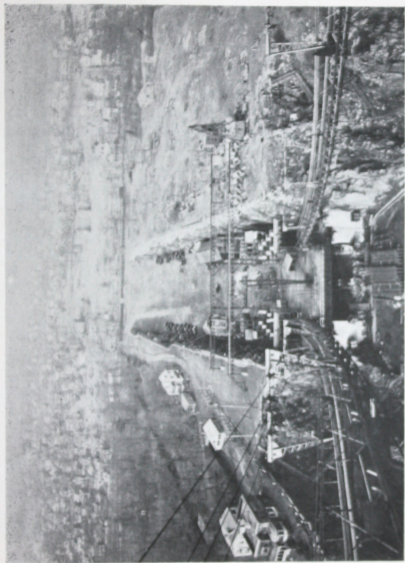


Longitudinal and transverse sectional elevations of New York anchorage, showing end of side span footbridge and location of principal wire spinning equipment. Main cable anchorage eyebars and girders not shown.

In New Jersey the cable wire reels and anchorage machinery and construction materials are handled by the girder crane that commands the approach cut and high level storage yard, and the relative positions of tramways, unreeling machines and tension towers correspond to those shown in larger scale at the New York anchorage.



At the New Jersey end of the bridge the construction plant was installed at three principal levels: storage yard, girder crane runway and cableway tower on top of the Palisades; unreeling machines, and some other equipment on the floor steel; and the remaining items in the anchor pits.



General view of New Jersey anchorage, showing reels of wire in spinning position.

\$600,000 TEMPORARY FOOTBRIDGE

All of the cable stringing operations are conducted from the tower tops, anchorages and their connecting footbridge, which must be maintained within about 2 feet horizontally and vertically, of its required position.

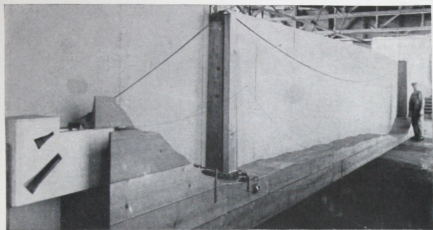
It is very difficult to fabricate ropes $2\frac{1}{8}$ inches in diameter and predict their structural set within the close limits of permissible variation of footbridge elevations. Even moderate variations from the expected structural set of ropes a mile long would so change the footbridge floor elevation as to interfere with the accuracy and speed of stringing the main cables.

The difficulty was overcome by subjecting the 108 long pieces of this rope to a stress of 200,000 pounds, which was maintained several hours, and then reduced to 80,000 pounds, which was equivalent to the load tension of the suspended rope. It was measured under this stress; the stress released; the rope cut as marked, and the ends socketed at the shops. When erected in position no irregularity of structural stretch was visible, and they serve together uniformly and with only very slight initial adjustment.

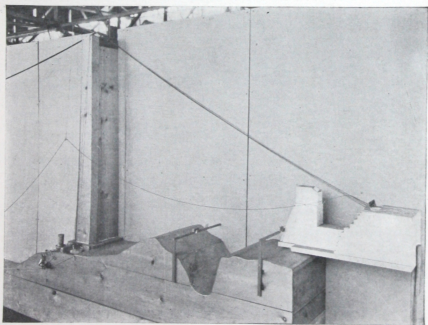


Footbridge cable ropes in position before final adjustment developed uniform stretch, producing great regularity and accuracy of catenary curves.

The footbridge is supported on thirty-six $2\frac{1}{8}$ -inch twisted Blue Center ropes, each about a mile long and weighing approximately 78,000 pounds. As these had to be, for erection, positioned from anchorage to anchorage with the center section lying on the river bed, a very careful preliminary study was made with a length and weight scale model rope and a very accurate 1/100-scale profile of the river bottom. This demonstrated the amount and character of longitudinal displacement of the rope and the eccentric stresses developed in hoisting it more than 600 feet to the tower tops, and determined the hoisting method and special equipment that were adopted and proved very successful.



1/100 scale model of profile of ground surface and river bottom and footbridge cable hoisting apparatus.

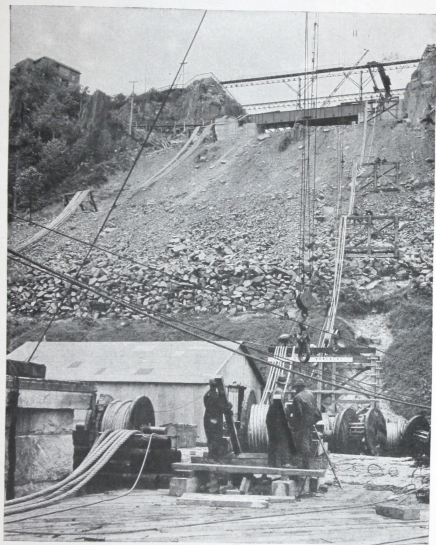


Model of footbridge cable rope hoisting equipment at New York side span.

POSITIONING FOOTBRIDGE CABLE ROPES

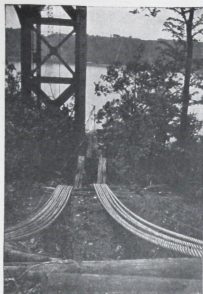
All the footbridge cable ropes except those for the west side span were unloaded from lighters near the foot of the east tower, the remainder being unloaded at the foot of the west tower. The side span ropes were positioned on both sides of the bridge axis from the shore lines to the anchorages, being supported on falsework trestle bents to keep them clear of rocks, etc., and the land ends were made fast to special anchors in the anchorage masonry.

The hauling of the footbridge cable ropes up to the anchor pits was made difficult by their great length and weight, and the necessity of supporting them on falsework bents between which they sagged in deep loops forming nodes that greatly increased the required traction force.

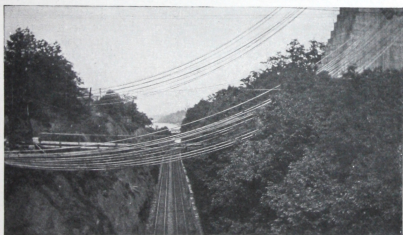


Hauling side span footbridge cable ropes to anchorage in Palisades.

Especial difficulty was experienced in positioning the New York side span ropes over the 300-foot span and 160-foot rise above the deep, wide cut for the New York Central Railroad tracks.

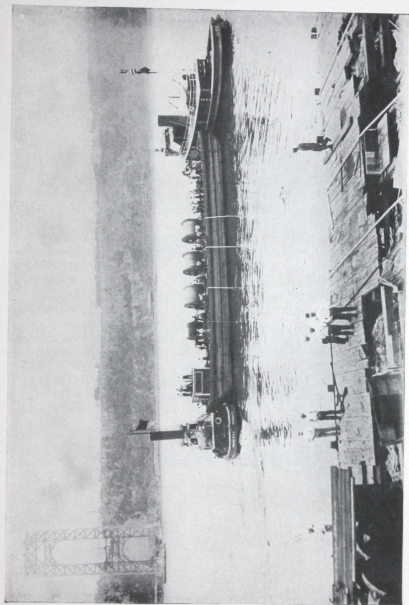


Footbridge cable ropes positioned for hoisting to top of New York tower.



Cable ropes for New York side span of footbridge ready to be hoisted over deep railroad cut.

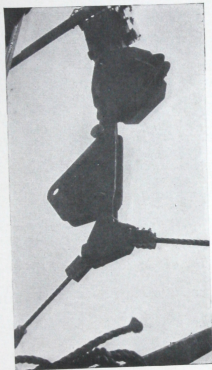
Each of two barges was equipped with four reel stands and reel brakes; the center span sections of the footbridge cable ropes on reels were placed in the reel stands, the socketed outer ends of the ropes were connected to the ends of the New York side span ropes, and the barges were towed across the river in about 20 minutes as the rope unreeled and dropped to the bottom of the river. The barges made alternate trips on opposite sides of the bridge axis, and when they arrived at the New Jersey shore the reel ends of the ropes were connected to the river ends of the side span ropes, making the footbridge cables continuous from anchorage to anchorage, but at an elevation 600 feet at the towers below the required height. Afterwards while navigation was controlled by a coast guard patrol for intervals of 1 hour or less, the footbridge ropes were successively hoisted to the tower tops in less than an hour each, and were placed in their saddles and adjusted to the exact required length and sag.



Laying a set of center span footbridge ropes on the river bed.

Hoisting, at two points, a stiff heavy rope, nearly a mile long, fixed at both ends, and submerged on an unseen bottom for more than half its length, becomes a serious matter when it must be rapidly raised to a great height.

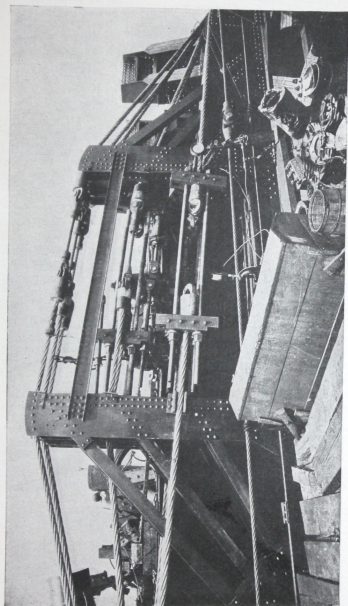
Investigations had shown that heavy longitudinal stresses would deflect the fixed points of attachment of the hoisting tackles about 70 feet from each tower towards mid-channel, thus pulling the heavily stressed tackles far out of plumb into positions that would be unsafe for the long flat derrick booms already installed on the tower tops. Therefore, the ropes were attached by multiple connection plates to tackles suspended from very sturdy cat-head girders cantilevering a short distance beyond the tower tops. When the ropes had been hoisted high above the surface of the river and the tackles hung nearly plumb, the boom tackles were attached to the connection plates, the cat-head tackles released, and the ropes hoisted the remaining distance and swung into position by the derrick booms.



Three-way connection plate permitting the hoisting tackle to be shifted from cat head to derrick boom.

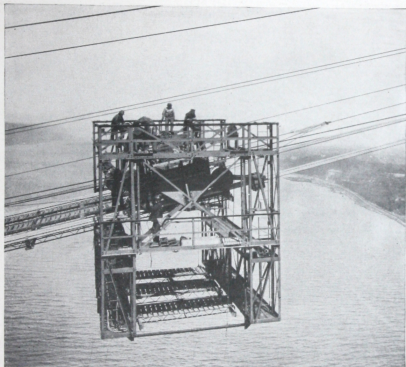
The footbridge cable ropes were supported on the tower tops on structural steel frames, the toggles connecting the socketed ends of the center and side span sections replaced by pulling jacks, and adjustments made and followed up by nuts on tension rods that joined the connections after the removal of the pulling jacks.

The footbridge, although generally spoken of as a single structure, really functions as two parallel duplicate working platforms 22 feet wide, that reach from tower top to tower top, and from tower tops to adjacent anchorages, one under each pair of cables. The center spans were erected simultaneously by four steel travelers working back and forth from the tower tops. The floor platforms were placed just below the groups of cable ropes in order that the latter should take the place of the specified guard planks, thus eliminating an important area of exposure to the wind.



Footbridge cable ropes in adjustment and supporting frame on tower top. Some sections of rope still connected by hoisting toggles. Other adjusted sections connected by pairs of tension rods.

Eight one-inch Blue Center traction ropes 5,400 feet long were taken across the river in pairs, and spliced to make four endless tramway ropes that were hoisted to the tower tops as were the footbridge cable ropes, reeved over fixed sheaves at the anchorages, and installed on the center lines of the main cables. Each was driven by a 100-h.p. motor at the tower tops. Attached to these traction ropes were trolley carriages traveling on the footbridge cable ropes and carrying large traveler cages for the erection of the center span footbridge.



Erecting traveler for center span footbridge. Note working platforms at different levels, floor sections on suspended platform, and safety rails.

ERECTING FOOTBRIDGE FLOORS

A temporary working platform was bracketed out from the river side of each tower just below the top, and to it were delivered the assembled 12x 25-foot standard steel floor panels, covered with wood gratings under the strand positions and with heavy wire mesh under the cable centers. They were loaded in sets of ten on platforms suspended from the travelers, and the latter with their crews were lowered by the tramways from the tower tops to the center of the span, where the erection was commenced.



Four traveling cages simultaneously erecting the center span north and south foot-bridges towards both tower tops.

Great rapidity of erection of the main span footbridge was attained by the installation and simultaneous operation of four erection cages that maintained the construction symmetrical at all times, loading the footbridge cables uniformly from the center to the towers.

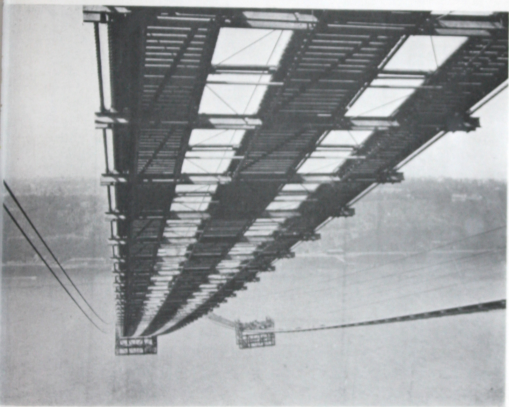
After the transverse bents supporting the traction tramways were successively erected, the five 14-ton crossbridges were hoisted to place from barges in the river.



Erection of main span footbridge showing the four erection cages at work. Also one of the five fourteen-ton steel cross bridges being hoisted more than 300 feet from the river.

The traveling cages for the erection of the center span of the footbridge were equipped with special trolley wheels with laminated wood treads that ran on the groups of footbridge cable ropes without abrading them or in any way impairing their strength and durability for their subsequent permanent service as suspenders for the bridge floors and trusses.

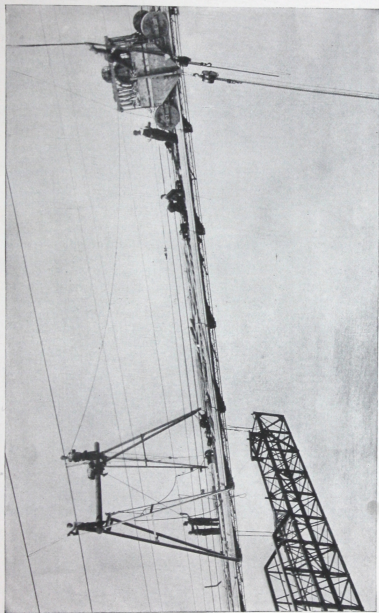
The arrangement of footbridge cable ropes above the footbridge floor enabled the erection cages to pass back and forth over the floor after it was erected in position.



Details of main span footbridge construction, showing how erection cages could be run out over the semi-completed footbridge.

The travelers also erected the transverse bents about 200 feet apart for the subsequent support of the spinning wheel traction ropes.

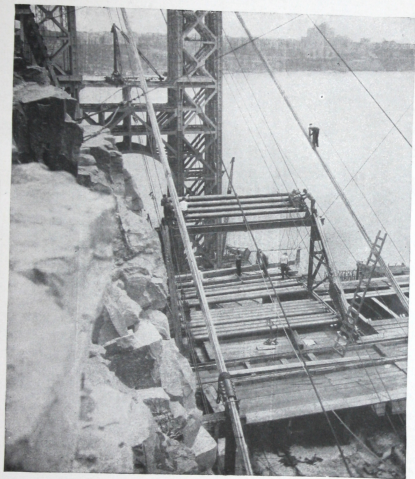
Each traveler was equipped with 600 feet of 1-inch Blue Center rope on a drum, and as the erection of the footbridges advanced, these ropes were passed over fixed sheaves on the transverse bents and lowered to the surface of the river, where pairs of them were made fast to opposite ends of one of the five 14-ton crossbridges. The travelers were then hauled towards the towers and thus raised the crossbridges, which were hoisted and bolted in position in less than an hour each.



Traveler carriage (with erection cage detached) hoisting one of the cross bridges from barge.

SIDE SPAN FLOOR ERECTION

On account of the steepness of the side span cables, their footbridges differed from those of the center span, and the floor panels were each made with three stepped sections 30 feet long parallel with the bridge axis, supported by 11-inch pipe floor beams 26 feet long and 30 feet apart, lying under and bolted to the lower cable ropes and suspended from the main groups of cable ropes. The steel longitudinal floor trusses have hook plates engaging the floorbeams at the upper ends and pin-connected to the plates at the lower ends of the adjacent sections.



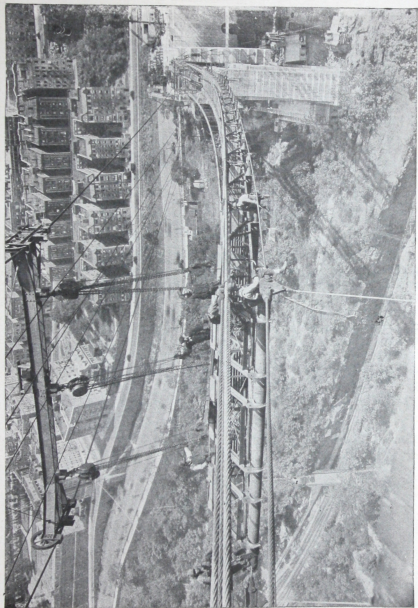
Erecting floorbeams for South footbridge of New Jersey side span.

Sets of four to six floorbeams, connected together by 30-foot tag lines, were loosely clamped over the lower footbridge cables, hauled up from the anchorage toward the tower tops, adjusted to accurate position by turnbuckles in the tag lines, and tightly clamped to the lower cable ropes.



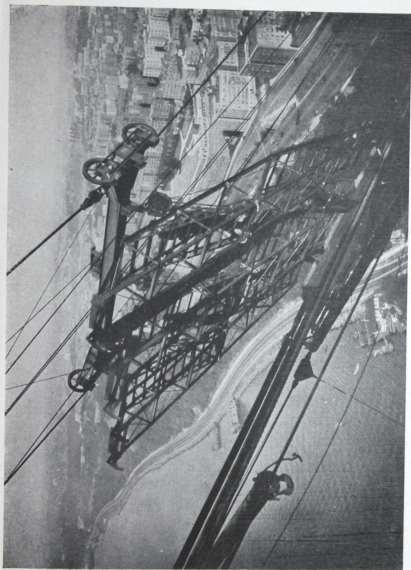
Side span footbridge. Floorbeams attached to lower cable ropes. Note working platforms in foreground traveling on overhead temporary tramway. Also, note upper group of footbridge cable ropes.

Over each footbridge there were installed two 1 $\frac{3}{4}$ -inch Blue Center side span tramway cables on which traveled the wheels supporting a movable carriage the full width of the footbridge. Each of these four carriages was equipped with a chain hoist over the center line of each of the three floor sections.



Assembling side span floor sections from platform suspended from 4-wheel carriage on tramway.
Note hook plate connections to floorbeam.

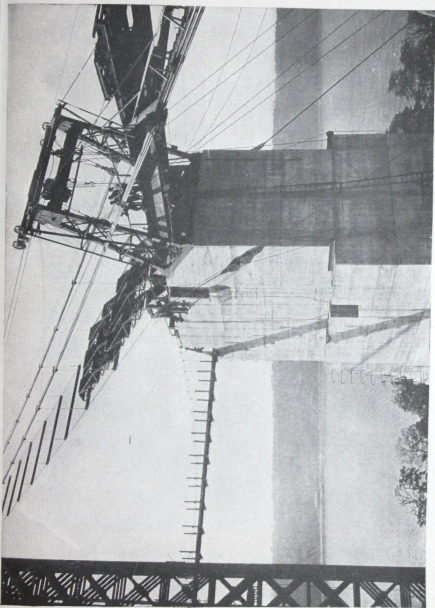
The three sections of one footbridge panel, connected together by their wooden floor platforms, were delivered at the anchorages to the carriages which were hauled up towards the tower tops by $\frac{3}{4}$ -inch Blue Center traction lines operated by electric hoists on the anchorages. Three men riding each carriage operated the chain hoists. The end hooks were lowered to engagement with the proper floor beams, and a gang following over the assembled sections made the pin connections at the rear ends.



Erecting last side span footbridge sections adjacent to New York tower by means of cableway.

The floorbeams, trusses, and platforms for the side spans of the footbridge, were assembled on pairs of low level ropes, and the floorbeams are suspended from the groups of footbridge cable ropes above.

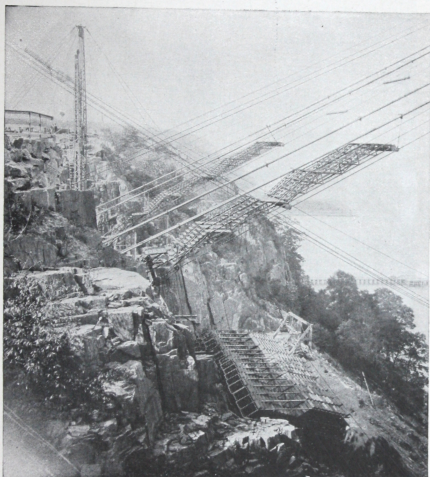
The trusses and floors were erected from light platforms carried under 4-wheel carriages running on temporary ropes above the footbridge cables.



Commencement of erection of north footbridge sections New York side span, showing floor beams suspended from cable rope groups. Note 125-foot span suspension service bridge with cables anchored to the concrete.

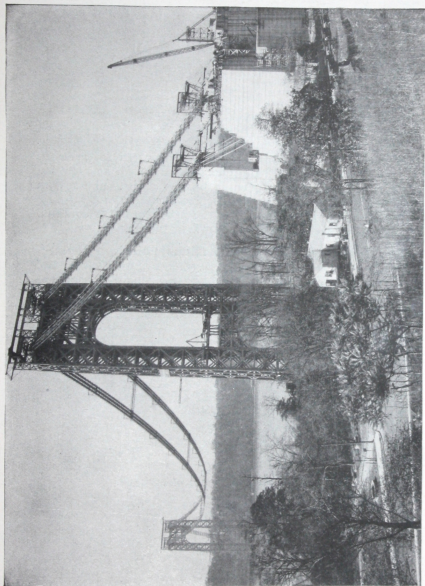
As the erection of the side spans of the footbridge progressed from the anchorages to the tower tops, the work was always accessible, and was advantageously performed from the assembled portions and from the light travelers that handled the floor sections.

The continuous working platforms thus provided just below the working points were most advantageous on the very steep inclines, and were an important factor of safety. No casualties occurred on this dangerous part of the work.



Partly erected footbridge for New Jersey side span. Note storage of floor sections in foreground.

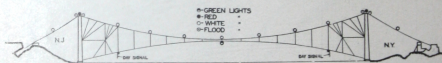
Less than eight days were required for the erection, without accident, of the two footbridges. During the footbridge construction the Company's launch cruised continually under the bridges to immediately render aid should it be needed.



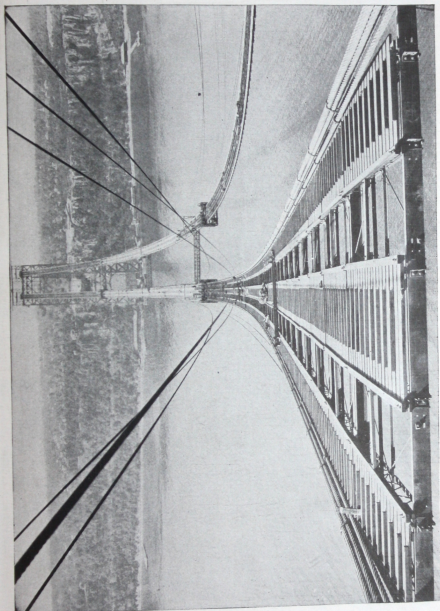
Completed footbridge from New York shore. Note Roebling construction towers on main towers, and tramway bents on footbridges.

The footbridge storm system cables were assembled immediately below, and supported from the footbridges, and their connections were made from the footbridge erection travelers. The booms and ropes were lowered to position. The counterweights in the towers were attached, and the adjustments were made by men in bo'sn's chairs. The system reduces vertical and horizontal displacements from a 60-mile wind, to about 1 foot and 3 feet, respectively. It contains about 75,000 feet of $\frac{5}{8}$, $1\frac{3}{4}$, and 2-inch rope.

Besides providing an ample illumination with numerous 200-watt lamps with domes, shades and reflectors for construction operations, the Roebling Co., maintains on the footbridge a complete system of all night traffic signal lights complying with United States and navigation requirements for aeroplane and marine traffic.



Footbridge storm system and location of lights.

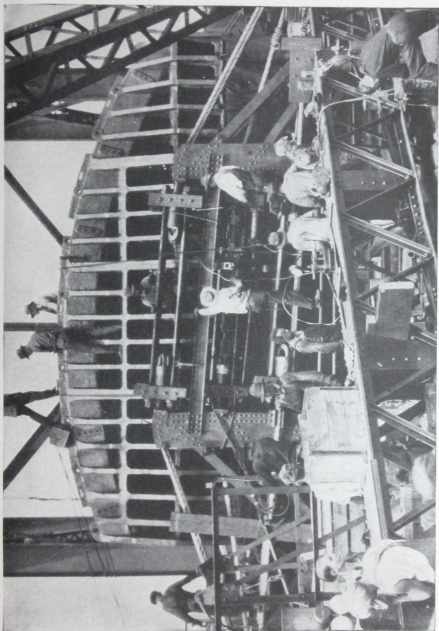


Center span footbridge before placing wire mesh under cables. Note cable ropes acting as guard planks.

Each of the 55 x 210-foot steel towers, 635 feet high, carries on its deep upper girders four massive sectional 180-ton cast steel saddles, grooved to receive the lower exterior thirteen $4\frac{1}{2}$ -inch strands of one main cable.

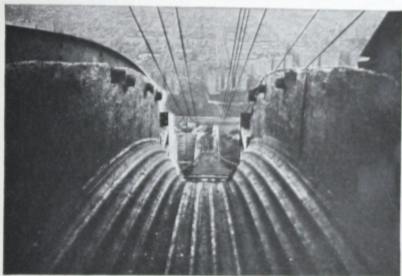
The erection and placing of these saddles required very powerful tackles, engines and boom derricks and was done with skill and safety; the hoisting engines, out of sight and hearing from the tower tops, being very accurately governed by the derrick man on the tower top, who controlled a set of electric signal lamps in the engine room.

The McClintic Marshall Co. hoisted and set these saddles, which were furnished and erected under the Roebling contract.



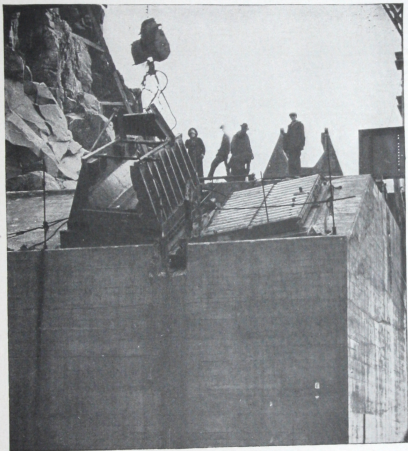
180-ton sectional cast steel main cable saddle. Temporary structural supports, adjustment jacks, and tension rods for foot bridge cable ropes in foreground.

The 61 strands of each cable are laid so as to have at the main saddle a hexagonal cross section, which, beginning on either side of the saddle, is eventually compressed to a circle by a massive yoke containing a number of powerful radial hydraulic jacks that will encircle the cable and, exerting an enormous force, will successively compact the cable wires and reduce to a minimum the interstices between them, after which the cable will be tightly wound by a protecting spiral wire.



Center span footbridge floorbeams and footbridge cables from New York tower top. Main cable saddle in foreground.

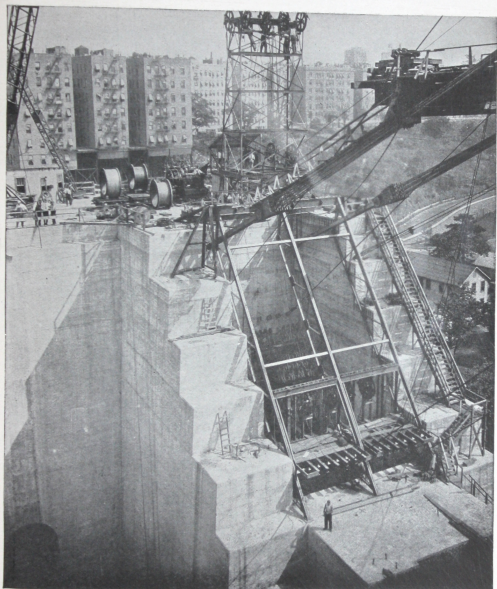
Over the anchor blocks, where the shore spans of the cables are deflected, they rest in 22-ton cast steel saddles supported on sets of rollers on thick bed plates inclined from the horizontal. These saddles were set in positions carefully computed, and allowances made for the longitudinal displacements of the saddles for changing cable stresses, longitudinal movements, and temperature variations.



22-ton anchorage cable saddle and roller bed.

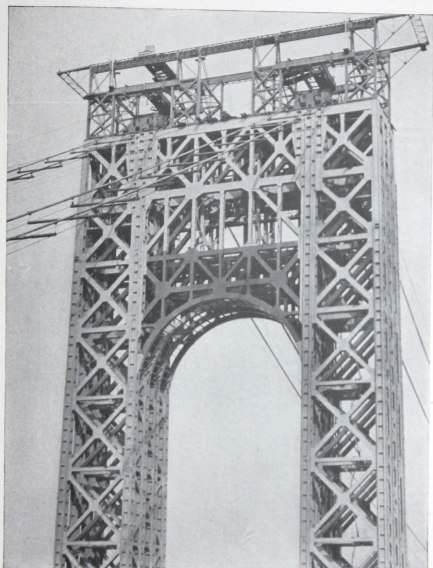
CABLE STRINGING EQUIPMENT

For spinning and adjusting the cable wires, and for adjusting, transferring and connecting the cable strands, there was installed on each tower top an auxiliary construction tower with 130-ton electric traveling crane; at each anchorage two 150-ton pulling jacks and two 60-ton hoisting jacks. There were installed for each pair of cables two tramways, eight wire unreeling machines with two hydraulic electric centrifugal power units, two wire tension towers, two hydraulic-electric wire splicing machines, and twelve electrically operated come-along clamps.



Wire reels, unreeeling machines, tension counterweight tower, and stiffleg derrick on New York south anchorage block. Footbridge cables and their anchorage eyebars in foreground. Strand anchorage eyebars under footbridge cables. Inclined spinning frame and adjustable spinning platform over anchor pit.

Integral with each construction tower is a transverse runway 245 feet long, cantilevering 21 feet beyond the north and south faces of the main tower for the $35\frac{1}{2}$ foot span girder crane, with two electrically operated pairs of 65-ton fixed hoists for lifting the cable strands. A $7\frac{1}{2}$ -ton auxiliary hoist is also installed on each crane to operate whip lines or tackles on its cantilever extremities.

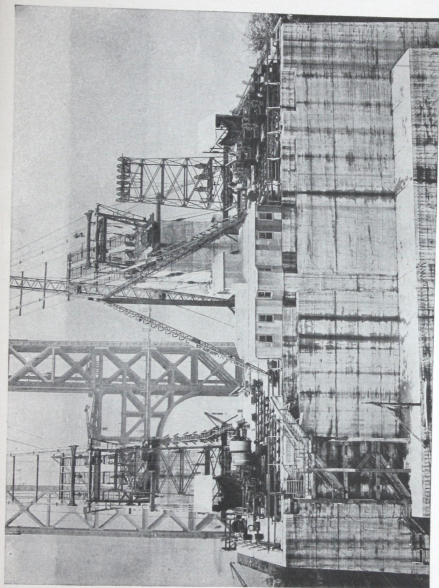


Temporary construction tower and girder crane on top of New Jersey tower.

The traction rope is driven at a speed of 600 to 700 feet per minute by a power wheel operated by a 100-h.p. motor at the New Jersey end, and at one end is reeved in multiple around pairs of movable counter-weighted sheaves that take up slack, and maintain uniform tension.

The previous use of the same rope for hauling the foot-bridge erecting travelers, very effectively produced complete initial stretch, and eliminated elongations in the wire spinning operations that would have caused great delay and loss.

A wire splicing press is installed at each end of each pair of cables, four in all. Each press has a circular yoke in which, at intervals of 120 degrees, are set three radial hydraulic cylinders operated at a pressure of 5,000 pounds per square inch to squeeze the nipple in their balanced dies with a force of about 100 tons, which causes the steel in the nipple to flow and produce a cold pressed joint that is as strong as the body of the wire.

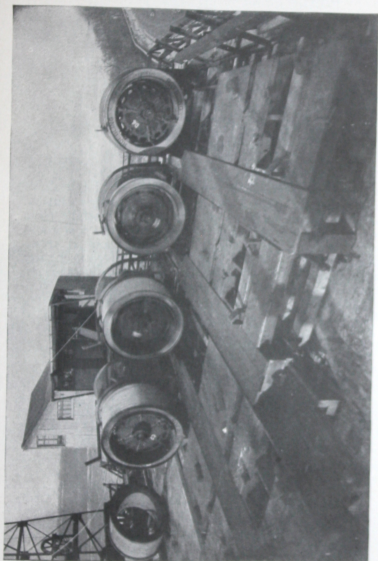


Cable spinning equipment installed on New York anchor block. Traveling cages erecting north and south side span footbridges simultaneously.

At each end of each cable there are installed two unreeling machines, sixteen in all. Each machine has a horizontal shaft with six adjustable radial arms, with their extremities fitted to engage the cylindrical inner surface of the wire reel that is moved over them parallel to the shaft; then the arms are extended to bear against the inner surface of the reel, thereby lifting it clear, and supporting it on the shaft.

Each group of four unreeling machines is operated by one 100-h.p. electric motor.

Watching the floating counterweight that maintains uniform tension in the wire, the machine operator regulates the speed of the unreeling machine to conform to the tramway speed.



Reels of cable wire mounted on unreeling machines at New York anchorage. Low level cars for shifting full and empty reels in foreground. Shelter for signalling equipment, reel controls and wire splicing machine in background.

In the plane of each main cable, and about 12 feet above its saddle, there is installed an aerial cable spinning tramway, with 1-inch Blue Center endless traction rope reaching from anchor pit to anchor pit, that is supported at the tower and anchorage saddles where the curves change, and at intermediate points, on sets of special sheaves that permit the free passage at high speed, of the two attached wheel carriages, and prevent vertical and horizontal displacement of the very long traction rope that has sufficient tension to engage the overhead idler sheaves.

Attached near opposite ends of opposite parts of the traction rope are the two trussed carriages, each equipped with a spinning wheel 4 feet in diameter, that carries a bight of bridge wire on each trip back and forth across the river.



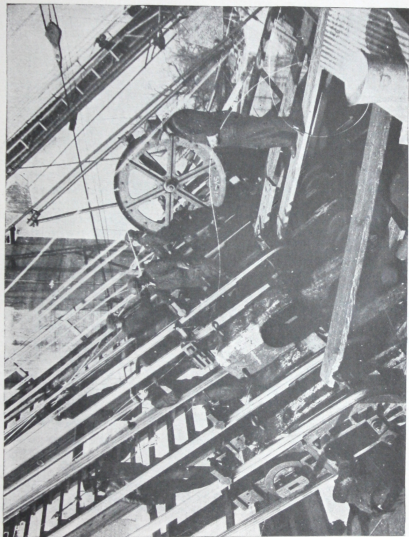
Spinning wheel laying wires in uncompleted strand of center span. Seized, finished strands underneath.



Strand arms connected to anchorage eyebars. Adjusting strands at New York anchorage.

A bight of the slack wire adjacent to the shoe is engaged with the spinning wheel, and in about 8 minutes is hauled across the river to the opposite anchorage, removed from the wheel and placed over the strand shoe there. The slack is pulled back across the river and its bight is picked up by the same spinning wheel and carried to the opposite strand shoe as before. Each and every one of the 434 parallel parts of a strand is an undivided portion of the same endless wire about 434 miles long, from many reels successively placed in the same unreeling machine; the end of each reel being field spliced to the beginning of the next reel. One spinning wheel is mounted on each part of the endless tramway rope that is reversed as soon as the wheels complete their trips from anchorage to anchorage, both wheels carrying loops of wire simultaneously across the river in opposite directions for different strands of the same cable. Each spinning wheel lays about two miles of wire on each trip across the river, and it now takes about nine days to spin one strand, all spinning operations being duplicated at both anchorages.

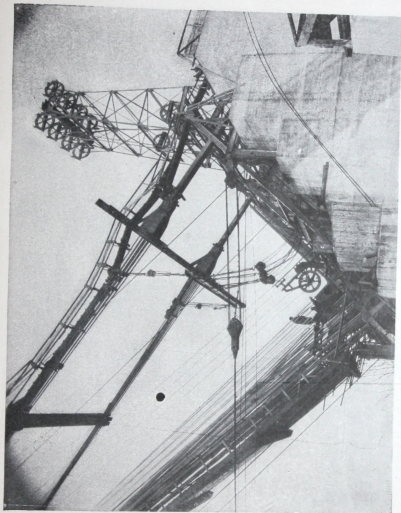
All the wires of every strand in the four cables are adjusted to exactly parallel a guide wire of the length and sag required for that strand. Each guide wire, identified by a copper wash, is of the same material, diameter and weight as a cable wire, and is about 5,199 feet long.



Removing wire loop from wheel momentarily stopped for reversal at anchorage. Note permanent strand shoe and strand connected to strand arm in spinning position at lower left corner.

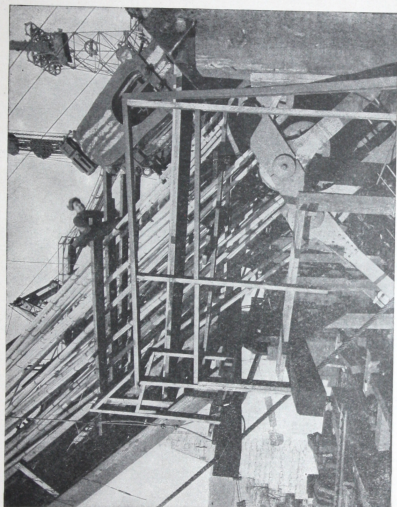
At the end of each one-mile trip in either direction between the anchorages, the tramway is stopped, and the bights of wire are removed from its two spinning wheels on opposite sides of the river. New bights of wire are put on the wheels, and the tramway is reversed to complete the round trips of its spinning wheels that are always traveling in opposite directions.

Stopping the tramway, shifting the bights of wire off and on both spinning wheels simultaneously, and starting the tramway in reversed direction, normally take only a few seconds.



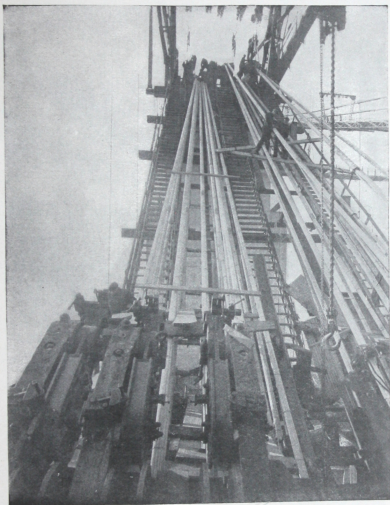
The end of a tramway trip: shifting bights of wire at the spinning wheel in center of lower part of picture. Wire tension tower at right.

At each end of each strand, the parallel parts of its wire are separated into two equal groups that together form bights of the continuous wire and engage the strand shoe. The wires of each group form semi-strands that converge at a small angle, and where they intersect are seized together to form a single cylinder $4\frac{1}{2}$ inches in diameter. These $4\frac{1}{2}$ -inch cylinders converge and merge into the 36-inch cylinder of the completed cable.



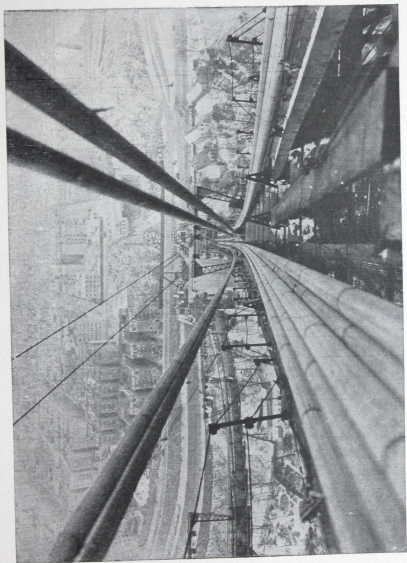
Lower tiers of strands connected to eyebars in New York anchorage, and working platforms prepared for spinning higher and higher tiers of strands.

After all the 434 wires of each strand are spun, the two divergent parts of the strand between the anchorage saddle and the strand shoe are separately seized before the strand shoe is transferred from the strand arm to its eye-bar connection.



Completing the construction of the strands after their spinning is finished.

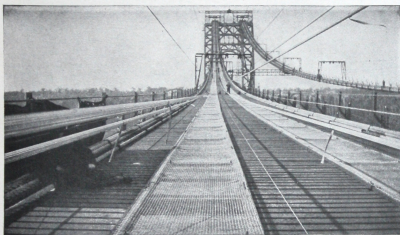
The profile of the footbridge was very carefully computed and adjusted so that it is very closely parallel to that of the cable, and is near enough to the latter to permit the men to work efficiently on the upper strands, and yet far enough from it to be free from contact with the lowest strands, thus eliminating the obstructions, uncertainties, changed stresses, delays, and dangers that would be caused by the contact of the cable strands with the footbridge.



Four strands completed and ready for adjustment with those already positioned in cable B.

The schedule calls for operations to be continuously maintained, in each working shift, in simultaneously spinning two strands for each of three cables, and adjusting two completed strands for the fourth cable.

These balanced operations are in regular succession without delay, interference, or lost time, and are carried on from a foot walk between each pair of cables, and from one on each outer side of each pair, six walks in all, besides the alternating spaces under the cables which are covered with wire netting instead of the wooden gratings on which the men walk and work.



Completed and incompleted strands spun on south center span footbridge.

The deflection of the side span strand from the center of its chord is measured by instrument readings as adjustments are made by the pulling jack on the basis of 1 inch jacking for 8 inches sag. Prior to the adjustment of the side span the center span of the strand is adjusted and verified by level readings on its center point.

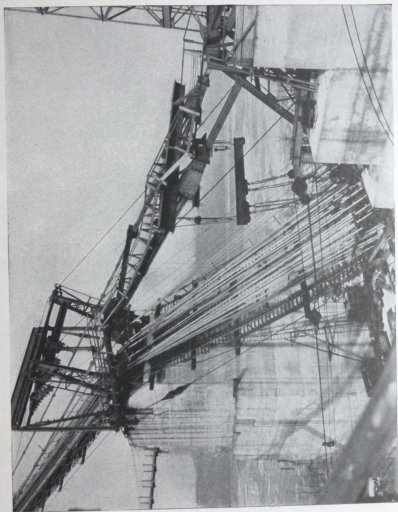
As soon as the center span adjustment is completed the second side span is adjusted like the first side span.



General view New Jersey side span footbridge, showing eight completed strands in each of the south main cables. Note transverse bent with tramway ropes and their supporting sheaves.

Special provisions are necessary at the anchorage for handling the heavy strand adjustment equipment, and to provide access between points at different elevations where various operations in are progress. Tackles are supported by a plate girder that is suspended from the footbridge cables, and transverse I-beams are clamped across the footbridge cables.

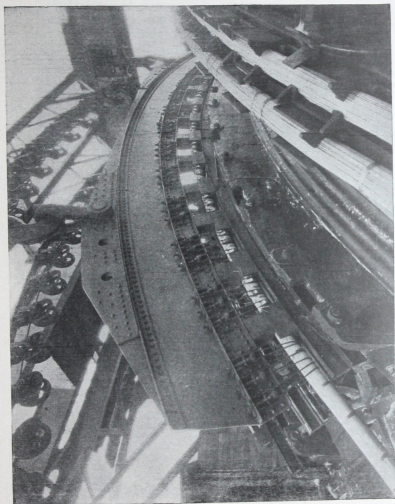
Curved girders suspended from a transverse bent on the anchorage saddle blocks, carry the sets of special sheaves supporting the traction ropes of the cable spinning tramways.



Cable wire spinning and strand adjustment equipment on north side of New York anchorage.

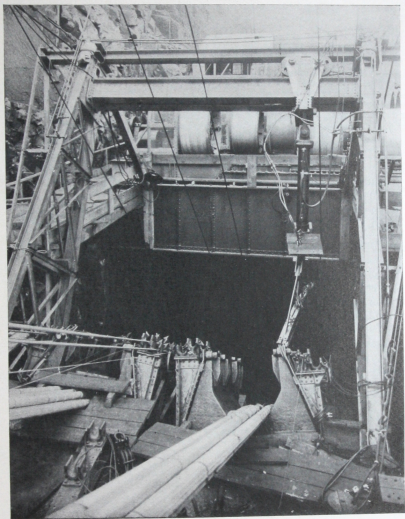
STRAND ADJUSTMENT

All the wires in a strand are seized together at 5-foot intervals. At the main and anchorage saddles grommets made of $\frac{3}{8}$ -inch wire rope are placed under the strand and their loops are engaged with bolts in a curved lifting beam above the strand. The grommet bolts are screwed up to lift the strand clear of its forming saddle, and the strand is shifted about $2\frac{1}{2}$ feet laterally to the center line of its saddle groove by traversing the crane hoist.



Curved lifting beam for transferring strands from temporary spinning position to permanent location in cable saddle.

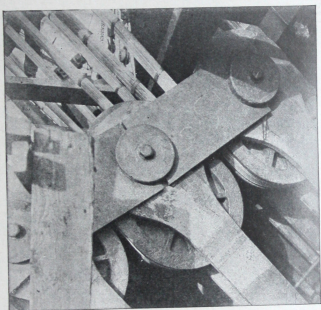
After a strand has been placed in its tower saddle, the anchorage saddle operator on the same side of the river lifts the strand with 60-ton hydraulic jacks, and moves it to lateral position with a hand winch. A 150-ton pulling jack moves the strand leg down for connection with the anchorage eyebars while the strand is being lowered into its saddles on this side of the river, and the same operations are repeated on the other side of the river.



Hoisting jack and lifting beam for setting finished strands into anchorage saddle.

Just beyond their supports in the anchorage saddles, the main cables are each divided into 61 strands that diverge in both horizontal and vertical projections to their connections with the upper panel anchor eyebars.

Each strand shoe is assembled between two eyebars and connected to them by a horizontal 10-inch pin, the ends of which project beyond the eyebars and engage half holes in spacer plates that are held in position by flat circular cap plates, secured by $1\frac{1}{2}$ -inch bolts passing through them and through the axes of the pins. The strand shoes have elongated pin holes permitting the exact adjustment of strand lengths by the insertion of shims in their bearings.



Typical assembly of cable strands to anchorage eyebars

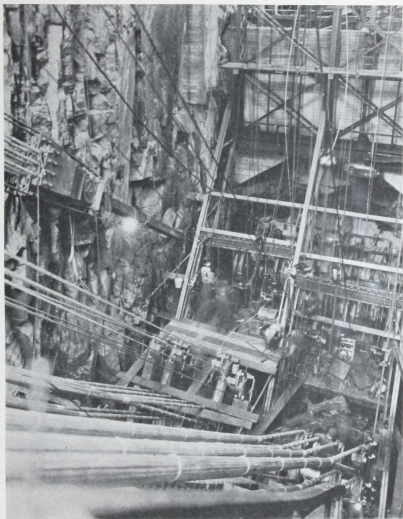
In the New Jersey tunnel anchorage, and the New York block anchorage, the strand shoes are spaced very close together in both vertical and horizontal planes, but the spinning and adjustment operations are so carefully planned that necessary clearances are maintained for handling the heavy equipment, and for transferring the strand shoes from the strand arms, to which they are attached during strand spinning, to the eyebars. The attachment of the strand shoes to the strand arms is well shown in the view of the first set of strands at the New York anchorage.



View of the first strands at New York anchorage. Spinning wheel at the left just starting for opposite anchorage.

As each strand is completed its shoe is connected to its anchorage eyebar, and the strand arm to which it had been secured during the spinning operations is detached from the eyebar and transferred to position to receive the shoe for the next strand while the latter is being spun.

These strand arms are very heavy offset steel castings, temporarily secured to the anchorage eyebars in such a way that they hold the strand shoe during the spinning of the strand, and then permit its permanent connection to the eyebar.



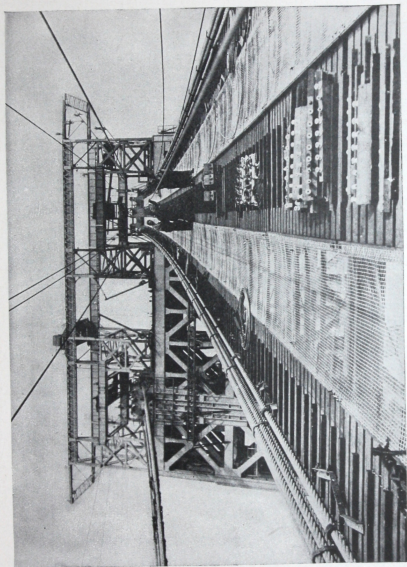
General view of New Jersey south anchor pit, showing some finished strands, and four strands being strung.

The exterior lower strands of the cables are carefully placed in their respective grooves of the cable saddles, and the interior lower strands are accurately set in their required positions tangent to each other, making the most compact hexagonal arrangement possible. The several horizontal tiers develop, in service, heavy vertical pressures on the lower wires, that have been carefully investigated by the Roebling Co.



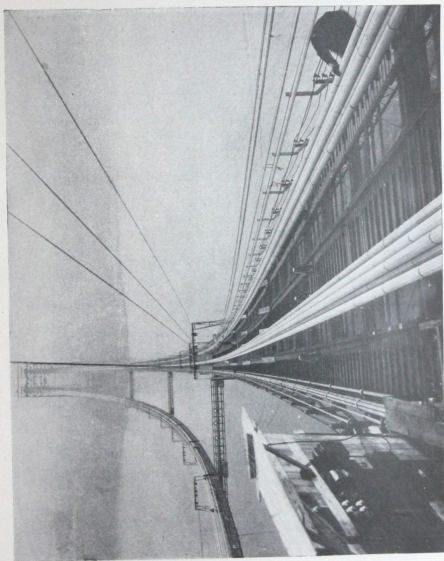
Eight finished strands in main tower saddle.

There is a very comprehensive and complete combination of eight principal electric signal systems covering and recovering all important locations and key operations of the work, and providing for telephone communication, light, bell, buzzer, and annunciator drop signals, instantaneously controlling and synchronizing spinning and adjusting operations, making possible the unprecedented speed that has been attained in cable stringing, and eliminating cable spinning delays that are estimated to cost at least \$125 per hour per cable in wages alone. The cost of labor and materials for the installation of the electric light, power and signal systems, exclusive of the cost of 86 electric motors up to 175 h.p. that furnish all power, was about \$60,000, and a force of 10 men is constantly employed on the maintenance of the electrical equipment.



Preparing upper end of center span footbridge for installation of electric signal systems. Note Roebling construction tower on top of main tower in background.

At the tower tops, at the anchorages, at the centers of the main and side spans, and at some other points on the footbridge there are located wind breaks and shelters, some of them heated in cold weather, where there are installed telephones and other equipment of the signal systems. The insulated electric wires are strung on steel posts adjacent to the hand rail ropes.



Groups of strands adjusted for each of the four cables. Note ample working spaces on both sides of cables, spinning tramways overhead, signal wires alongside hand rails, and signal station at left.

VITAL ROEBLING DEVELOPMENTS

In the design and construction of suspension bridges and bridge cables, uninterrupted since 1849, John A. Roebling and his successors have originated and perfected many features essential to the success and safety of the Hudson River Bridge cable work, among them being the following:

- The use of wire spinning wheels.
- The aerial cable spinning process.
- A new type of wire spinning wheel and wheel carriage, eliminating the goose neck that limited spinning speed.
- Tramways for cable wire spinning.
- The use of erection footbridges.
- Wire mesh flooring for erection footbridges.
- Sectional footbridge cables.
- Erection of footbridges by tramway carriages.
- Erection of footbridges from mid span to towers with increased rapidity and safety.
- Storm system independent of footbridge.
- Automatic counterweight adjustment for storm system.
- Maintenance of uniform cable wire tension by counterweights.
- Cable wire splices of practically 100% efficiency.
- Power adjustment of cable wires.
- Power driven and power braked cable wire reels.
- Improved tramway supporting sheaves.
- Instantaneous central control of all wire spinning operations.
- Stringing cable wires on strand shoes in vertical planes.
- Suspended compression booms in storm system.
- Preliminary straining of footbridge cables and tramway ropes.



Illumination of tower top and footbridge visible to millions of people within a radius of several miles.

